Army High Performance Computing Research Center

AHPCRC Bulletin

Volume 1 Issue 2

Distribution Statement A: Approved for public release; distribution is unlimited.

Network and Information Sciences

Today's soldiers are links in communications networks that include sensors, data processors, and humans. *ARL graphic*

The days when Army field communications consisted of signal flares, telegraph messages, and couriers on horseback are long gone. Today's warfighter depends on speed-of-light communications and data transmission in order to react quickly to threats and changes in circumstances. Unfortunately, a proliferation of communications devices takes an ever-larger share of scarce space and power resources in Army vehicles and backpacks. Complex networks must balance the need for accessibility with security, speed, and accurate transmission.

In this issue of the AHPCRC Bulletin, we introduce the four projects in AHPCRC's Computational Battlefield Network and Information Sciences Activities technical area and the researchers working on these projects. Also inside: news from the AHPCRC consortium partners at Morgan State University and the NASA Ames Research Center.

WWI-era handmade radio that reported the news of the WWI Cease Fire

GI Joe, a U.S. Army homing pigeon, delivered a message during WWII that saved the lives of 1000 Allied troops.

Photos at center and bottom: U.S. Army U.S. Army Communications Electronics Museum, Fort Monmouth, NJ

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **AHPCRC (Army High Performance Computing Research Center) Bulletin. Volume 1, Issue 2, 2011**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army High Performance Computing Research Center,c/o High Performance Technologies, Inc,11955 Freedom Drive, Suite 1100,Reston,VA,20190-5673**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**20**	

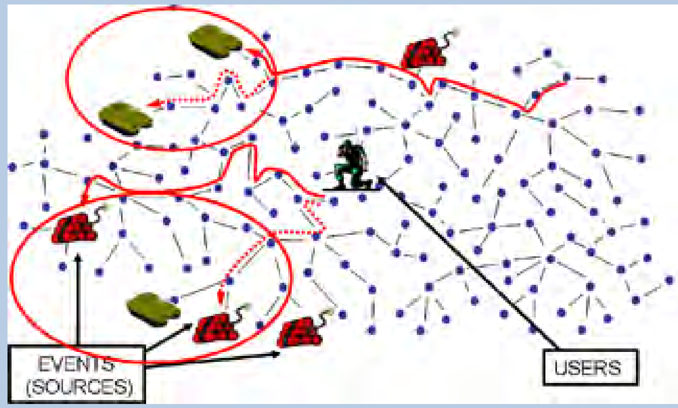
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Information Aggregation and Diffusion in Networks

Getting the information you need, when you need it, in a usable form, is a persistent challenge to effective military operations. Great strides have been made in linking individual sensors (including the human variety) into wireless networks, but the sheer amount of raw data transmitted over a large network makes it impossible for users to take in, much less interpret and use, most of the data coming in. Situational awareness demands that incoming data be timely, relevant, and interpreted in order to make quick, effective decisions. Ideally, network users should be able to respond proactively as situations arise in their areas of operation, rather than responding reactively to information that has been routed and processed through a central command.

High-performance computing (HPC) is being explored as a means of designing and optimizing large-scale simulations of communications networks, allowing developers to try out many configurations and choose the most efficient one for a given purpose. HPC resources can also be incorporated into real-world communications networks to optimize deployment and performance. Data collected during actual network operations are streamed to HPC servers at the periphery of the network for use in fine-tuning the network and adapting to changes in the environment and traffic load distributions as they occur.

Leonidas Guibas, a professor of computer science at Stanford University, is leading a group of Stanford researchers in providing low-latency, highly-specific sensor network data delivery to mobile users, in the support of live operations and live network configuration and analysis. Collaborators on this project include Phil Levis (assistant professor of computer science and electrical engineering), HyungJune Lee (graduate student, electrical engineering), Nikola Milosavljevic (graduate student, computer science), and Brano Kusy (postdoctoral associate in computer science). The group also envisions a social-network style user collaboration to aid in the interpretation of sensor data through multi-user data annotations and recommendations.



Lightweight Anycast in a Dynamic Environment

Mobile Users

In today's sensor networks, the users don't sit still—this is one factor that limits the performance of these networks. Existing network protocols perform progressively less well as users become more mobile, to the point where a network may be unable to find a route to a highly mobile user. Data may be sent to the wrong location or not arrive at all, congestion can develop as a result of inefficient routing, or data may need to be transmitted more than once. Any of these factors can slow the overall travel time between sender and receiver (increased latency, in the language of network designers) and waste precious network resources, such as bandwidth and battery power.

When a user (human or data-processing sensor node—a "data sink") moves, the routing data structure must be updated, and data packets en route to the sink must be re-routed to the new location. A brute-force way to accomplish this is to distribute all the data packets all over a network cluster (cluster-wide flooding). This method is resource-intensive, to say the least. Timely prediction of the data sink's next communication neighbor, as the sink moves around, makes more efficient use of network resources. Guibas' group is currently exploring RSSI-based neighbor prediction techniques. (RSSI, Received Signal Strength Indication, is a measurement of the power present in a received radio signal.)
In particular, they are examining locally weighted

linear regression, Gaussian process regression, and discrete path selection after global topology discovery, based on training sample sets.

Travel Time

Latency, the time it takes for a signal to travel from the sender to the receiver, depends not only on the distance traveled, but also the number of nodes along the way, the bandwidth of the communications channels, and the level of network traffic. The Stanford group is working to reduce the distance that signals must travel along low-bandwidth ZigBee links by first routing data from the originating sensor to clusterheads, which cooperate to find a cluster where the data sink is located and deliver data to this cluster over high-bandwidth Wifi links. Data packets again travel along ZigBee links in the final part of the route.

Routing data from its source to a clusterhead is straightforward from the networking point of view—any collection tree protocol works fine. However, there are several alternatives for transmitting data from a clusterhead to a sink. Guibas' group is currently exploring cluster-wide flooding, point-to-point routing, route-to-sink along collection tree, and sink-centered collection tree approaches.

Relevant Data

Because sensors collect large amounts of data, even when nothing interesting is happening most of the time, some level of data filtering is necessary at the sensor level. The team is looking into techniques for coarsely classifying raw data streams (human, vehicle, explosion), to find abstract classifiers of data streams (flow of people, occupancy metric), and to collaboratively detect events (shot, alarm, loss of contact, wrong way motion). Clusterhead nodes can provide higher level data classification and additional reliability by fusing data from multiple sensors (total building occupancy, homing in on a shooter's location).

Information brokerage is the technique of matching sensor data to a user's interests. Even if most of the irrelevant sensor data are filtered out at the sensor or clusterhead level, constraints on sensor node resources do not permit high-level data interpretation. Humans can aid in the interpretation of sensor data, especially data that they can easily comprehend (images, video, or audio), but limitations on the amounts of data that can be sent over a sensor network requires that most data remain at the node. Selected data are sent to the user for interpretation, in most cases, when the user is geographically close to the sensor. Tags or labels (data annotations) can be added to aid in interpreting data, which are then transported in a compact fashion throughout the network.

Directing Traffic

If too many nodes in the network are firing (performing an action) all at once, the result can resemble rush hour in midtown Manhattan—it takes longer to transmit a signal from sensor to user, and it is much more likely for a signal to be misrouted or lost. For a network to perform efficiently, each node must fire when its neighbor is not firing. Ideally, a fast, lightweight, distributed protocol would coordinate neighboring nodes using only local connectivity information, adding a minimum of overhead in the form of communication and computation.

Desynchronization applications provide periodic resource sharing, allocate tasks among nodes, and spread the sensing burden evenly among nearby nodes to avoid redundant data collection. Each node's on/off schedule is coordinated with its neighbor, thus lessening the chance of a collision between data packets.

The researchers use a technique in which the nodes in the network select a random firing interval. Nodes "listen" during their proposed interval and check to see if any neighbor has also claimed that interval. If the node detects no conflict, it claims that firing interval by oscillating at a common frequency, and it always fires during that chosen interval. If there is a conflict, the node selects a new trial interval with a randomized choice. This repeats until all nodes have settled on suitable firing intervals.

Power and Portability

In this context, the term "lightweight" refers to protocols and methods that maintain the longevity of the

continued on page 10

Robust Wireless Communications in Complex Environments

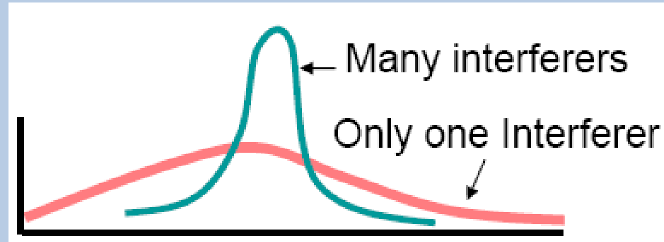
During the last decade, the commercial wireless communications industry has made significant progress in enhancing coverage and mobility and achieving high spectral efficiency. Civilian wireless technology is typically some generations ahead of military technology because of the sheer size of the mobile communication market, which attracts huge investments in technology development, according to Stanford electrical engineering professor Arogyaswami Paulraj. However, he said, these commercial providers have not generally addressed issues of performance in complex military scenarios. Effective military wireless communications require robust networks and links that are capable of operating in complex environments, especially in dense urban neighborhoods. Such networks must resist hostile jamming while keeping low power at terminals.

"These days an army marches on its batteries," Paulraj said in a Stanford press release. During the Gulf War, the Army had to bring in jet transports full of batteries to meet the demand. Smart antennas can reduce battery drain substantially, Paulraj said, because they can transmit radio energy only in the required direction. That capability also can make it more difficult for hostile forces to intercept radio signals, and it can make "spoofing"—the generation of disguised messages by enemy troops—more difficult.

Designing a Better Network

Arogyaswami Paulraj and George Papanicolaou (professor of mathematics at Stanford University) are leading a research group that is using high performance computing technologies to optimize generic transmission and signal processing algorithms, exploiting link level OFDMA, MIMO, OS, and TR techniques for a complex environment. *(See sidebar for explanations of abbreviations used in this article.)*

Collaborators include Stanford visiting scholar S.J. Thiruvengudam; postdocs Aydin Sezgin, Gokman



Interference diversity increases overall link reliability.

Altay, Nicoli Czink; and Ph.D. students Mohammad Charafeddine and Stephanie Pereira, all of Stanford.

The group plans to extend the simulation and optimization bench to go beyond the link level to include multiple (say 100) users simultaneously using the network in a complex urban environment. This will make the design challenge significantly more complex. However, this step will enable a much higher degree of design confidence and can better support full-scale development of such systems by industry.

Additionally, the team will explore the application of HPC simulation to developing DoD imaging and sensing systems. Eventually, these methods will be optimized by large scale numerical simulations on high performance computing platforms and verified and validated in collaboration with the Army.

The research team has analyzed realistic PHY (physical interface) models for battlefield networks. They have studied IM (interference management) using opportunistic scheduling, power control, and dimension orthogonalization. They have made TR (time reversal) channel measurements in indoor scenarios.

In a presentation he gave last November, Paulraj explained several features of IM:

- *Cooperative Encoding:* If nodes can be treated as one giant array, then the effects of interference can be eliminated altogether (Costa's Result) by proper coding.
- *Power Control:* For each inter-node interference scenario, there is a unique solution to the optimum transmission power levels to maximize throughput.
- *Opportunistic Scheduling:* Unlike in wired networks, wireless communications channel conditions

Abbreviations and Acronyms

BN battlefield network

CSI code structure identifier

IM interference management

HDB high delay bandwidth

LT Luby Transform codes

Certain networks, such as ones used for cellular wireless broadcasting, do not have a feedback channel. Applications on these networks still require reliability. Fountain codes in general, and LT codes in particular, get around this problem by adopting an essentially one-way communication protocol.

MANET mobile ad-hoc network

MIMO multiple-input, multiple-output

MMSE minimum mean-squared error

OFDMA orthogonal frequency-division multiple access

OFDMA improves network coverage, since terminals can choose reduced bandwidth transmission to increase their range and reach a distant base station. OFDMA is not available in WI-Fi. (*2*)

OS opportunistic scheduling

Typically in a wireless system, the signal strength bobs up and down (fades). In WiMAX, we monitor these swings and schedule transmission when the signal is strong. This can improve throughput by about 50%. (*2*)

PHY physical interface, or transceiver

Rx receiving (reception)

Tx transmitting (transmission)

TR time reversal

In a basic TR communications experiment, the intended receiver first broadcasts a short pilot pulse. The transmitter estimates the channel impulse response and then sends the time reversed version of it back into the channel. The emitted "time reversed" waves back propagate in the channel by retracing their paths and focus in space and time at the source, the intended receiver. (*1*)

UMB ultra-mobile broadband

WIMAX worldwide interoperability for microwave access

Wi-Fi (also known as 802.11) works well in offices, cafes, and outdoor "hotspots," but if you move across town you'll quickly lose coverage. WiMAX is a wireless data network that can cover an entire city, just like cell phone networks do today. WiMAX (or 802.16) provides speeds comparable to Wi-Fi—between 1 and 10 million bits per second (Mbps) for individual users. So with WiMAX, you have the best of both worlds—mobility and speed. (*2*)

vary with time and location. Signal resources can be used more efficiently if they are allocated to network links that have good channel conditions and away from these links during poor channel conditions.

- *Spatial Filtering:* Minimum mean-squared error (MMSE) interference cancellation involves linear filtering at Rx and interference avoidance at Tx.
- *Interference Diversity:* Since users tend to be in random independent locations in the network, fluctuations in interference are reduced when they are averaged over many users in the system, making links more reliable overall.

Advantages offered by TR include spatial focusing, temporal focusing, and channel hardening. Spatial focusing, in which the spatial profile of the power peaks at the intended receiver and decays rapidly away from the receiver, reduces co-channel interference in a multi-cell system and increases the efficiency of bandwidth usage in the overall system. Temporal focusing produces a very short effective length of the channel impulse response at the receiver, which reduces the complexity of the equalization task. "Channel hardening" refers to the tightening of the distribution function of the effective channel impulse response. Thus, the time-reversed channel has a much smaller variance than the physical channel itself. (*1*)

Focusing energy spatially and temporally at the intended receiver reduces the probability of signal interception. Time reversal techniques improve link reliability by increasing diversity, which reduces signal fading by generating a number of signal transmission paths, or diversity branches. Each branch carries the same information signal, but multipath fadings of each branch are not correlated. Diversity branches are recombined at the receiver to resolve the transmitted signal.

The Stanford group is interested in exploring applications for the very rich diversity offered by HDB channels. One possibility is improving the spatial multiplexing in MIMO systems. Coding strategies must be developed to exploit rich-diversity channels.

The research team is developing performance tools

continued on page 11

Secure Data Dissemination and Aggregation

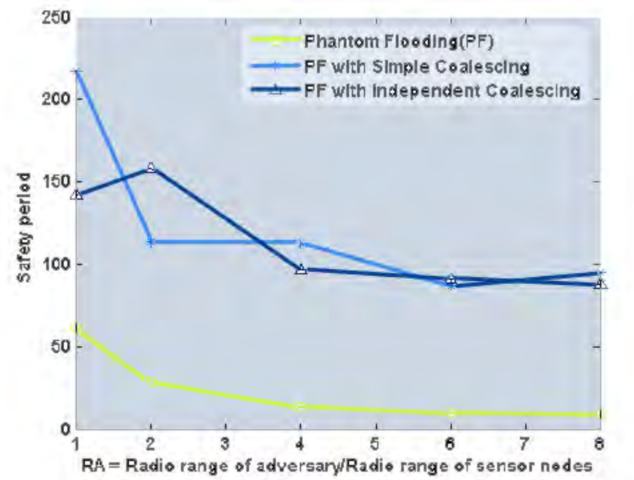
A wireless sensor network offers the opportunity to observe the physical world with unprecedented spatial and temporal detail. Sensor nets used for military purposes must address security and privacy concerns to a greater extent than civilian sensor nets, because an unsecured network can be co-opted or used just as effectively by an adversary.

Battlefields rely heavily on information and communications for situational awareness and rapid response to changing conditions. Data security and privacy are essential, but the constraints that security places on a communications network must be balanced with the need for fast, efficient in-network processing.

To optimize the complex tradeoffs between processing, security, communication bandwidth, and power consumption in such a setting will push the frontier of high performance computing, according to Amiya Bhattacharya and Hong Huang, assistant professors of computer science and electrical engineering, respectively, at New Mexico State University. They are developing new protocols and methods specifically for operation in a complex battlefield-like environment, where nodes are mobile and wireless channels are subject to fading, interference, obstacles, and other adverse conditions.

What is required to perform sensing tasks in the context of a battlefield? How does one specify these tasks in a high-level computer language? A sufficiently general model of the sensing tasks is needed, as well as a means to capture the uncertainties related to throughput, deadline, privacy, and security in terms of information theoretic measures. Criteria must be established to determine which existing cryptosystems and related key-distribution schemes are amenable to the adaptive protocols for achieving the intended optimization.

Bhattacharya and Huang are working to develop prototype designs for new techniques to enhance data security and privacy methods particularly suited for sensor nets with in-network processing. They are also optimizing the balance between data security and in-network processing.



Relative safety periods (time to source capture) as a function of relative receive range of adversary

Their future plans include integrating the sub-problems of the optimization and the optimization, simulation, and validation of new methods and protocols covering all relevant parameter space of battlefield network environments. The parameters of the network environment include channel condition, network size/topology, sensor density, sensor types/capabilities, node movement pattern, event generation rate/pattern, as well as adversary models and strategies.

This effort is divided into two subprojects: developing secure data aggregation methods that limit the risks from data falsification by adversary, and developing dissemination protocols for protecting the contextual privacy of sensor data (along with the privacy of the content) against traffic analysis by an intruding adversary.

The team has simulated the relative energy consumption rates of sensors in probabilistic sensor data aggregation. *(See sidebar for an overview of this method.)* They found that that they can retain balanced energy consumption using the probabilistic data aggregation scheme under development. This new scheme reduces security risk by making it more difficult for the adversary to compromise sensor data aggregation. They have also obtained some preliminary results in their studies of relative safety periods (time to source capture) as a function of relative receive range of an adversary.

They plan to set up and run simulations to validate the secure sensor data aggregation method. Spatial obfuscation of the source location will be formulated in terms of the RF (radio frequency) exposure created by sensor data flow. Routing protocols will be designed and simulated by composing available micro-protocols.

Dr. Huang and his students have finished the preliminary design and simulation of a number of sparse and dynamic in-network data aggregation (SDDA) schemes for sensor nets. The proposed schemes seek to balance the benefits of data aggregation with the associated security risks. The SDDA schemes select a subset of nodes as aggregators in a dynamic fashion to frustrate adversaries. Simulation results demonstrate that the new methods can achieve the reduction of security risk at the expense of a moderate increase in communications cost.

Dr. Bhattacharya and his student have been working on a protocol synthesis approach for designing an optimal sensor data routing protocol in terms of power–privacy tradeoffs. Phantom routing, a well-known privacy preserving routing protocol, has been decomposed into its constituent atomic protocol primitives. These primitives are being implemented as modules for use in Ns2 based simulation. (Ns2 is an open-source discrete event simulator for conducting networking research.) Initial studies have shown that phantom routing is sub-optimal, but a recursive version shows potential for optimality.

Analytical work using entropy as a metric is underway, so that the parameters of the recursive formulation can be theoretically determined. Both the original and the new recursive version of phantom flooding will compared using the simulation being developed using the protocol synthesis framework in the near future.

continued on page 10

Data Aggregation

The topic of in-network data aggregation has gained importance in the wireless sensor networks community over the last several years. For nearly all node technologies, data transmission over wireless links costs hundreds to thousands of times more energy than performing local computation on the same data. For untethered, energy-constrained (e.g., battery-operated) sensor nodes monitoring a physical environment, energy conservation and network lifetime considerations become significant, and it is desirable to trade local computation for communication as much as possible. Sensor nodes can be equipped with computational capabilities, so that they can compute and transmit cumulants, moments, or summaries directly, thus avoiding the expensive transmission of all sensor data to a (possibly distant) base station.

After an aggregation tree or forest is formed, data aggregation can be conducted by having the data flow up the tree and aggregated in the standard way. Data aggregation can be integrated with the tree formation process so that they both happen simultaneously. In the tree formation procedure, random priorities are used to determine which probe message should proceed. These random priorities can be used to implement data aggregation, by using probabilistic counting techniques. Essentially, the formation of the tree achieves the computation of the minimum of some random numbers chosen by the hot nodes, with which one can derive an approximation to the final aggregation value. Because the aggregation is done by computing minima, the framework is robust with respect to such factors as packet duplication and multiple encounter events between packets from the same two nodes.

Reference:

Jie Gao, Leonidas Guibas, Nikola Milosavljevic, John Hershberger. Sparse Data Aggregation in Sensor Networks. *IPSN'07,* April 25–27, 2007, Cambridge, Massachusetts, USA. (Available at http://www.stanford.edu/~nikolam/downloads/gghm-sdasn-07.pdf)

Parallel Solvers for Complex Antenna Simulations

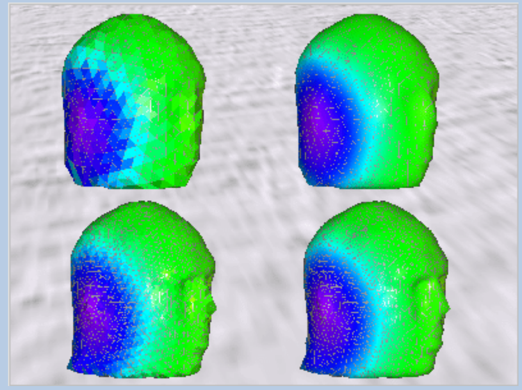
The computations necessary to design and build complex systems of antennas, which can contain millions of components, require an equally complex system of algorithms. The the behavior of the electromagnetic field within each component must be analyzed while taking into account the effects due to materials and other parameters that support and connect the components to one another.

Especially in the high-frequency regime of microwave and millimeter wave integrated circuits, the sheer numbers of components and the mesh resolution required for analysis makes high performance computing an essential tool for solving design problems and identifying and addressing factors that can limit the performance of these networks.

Gregory Wilkins, professor of electrical and computer engineering (ECE) at Morgan State University, and Charbel Farhat, professor of mechanical engineering at Stanford University, are developing fast, scalable parallel iterative solvers for large-scale electromagnetic calculations, with the assistance of Morgan State ECE students Razid Ahmad (undergraduate) and Babafemi Talabi (graduate). They will apply these problem-solving algorithms to the innovative design of antenna systems with millions of components and to creating computer simulations to assist in optimizing these designs. Shauna K. Henson (2006 ECE graduate) is working as operations coordinator for various aspects of the project, assisting with both research and outreach.

The Project to Date

The essential parts of the computing system are under development. Ahmad has been instrumental in configuring the computer network and investigating additional hardware components, such as servers. Licensed software will be loaded onto the system to allow multiple users to gain remote access to the centrally-located software tools necessary to complete the research effort. These tools will be essential



Example of finite element model with four mesh resolutions (NIH graphic. See *Terms and Explanations*, next page).

for future computational electromagnetic simulations and will form the basis for the high-performance electromagnetic research program.

The group is working to develop, then verify and benchmark, a FETI-DPM (finite element tearing and interconnecting–dual/primal Maxwell) solver for Maxwell problems. (Maxwell's equations describe the behavior of electrical and magnetic fields, such as those produced by antennas.) The solver will include modifications that allow for rapid changes, or sweeps, in the frequencies of operation of the antenna. In addition, the algorithm will be generic, allowing for multiple interactions in regions of varying material parameters, otherwise known as heterogeneous media. The algorithms will be developed and written in the form of a stand-alone, portable, massively-parallel code of the type used by supercomputers and high-performance computing clusters. The plan is for this stand-alone module to be fully integrated into Morgan State University's computational electromagnetics (CEM) code, which will be delivered to ARL. In the longer term, a parallel AMR (adaptive mesh refinement) capability will be integrated into the CEM codes and optimally connected to the FETI-DPM solver. The resulting package promises to be among the fastest finite element modeling-based CEM solvers. *(See the sidebar for a description of some concepts and methods discussed in this article.)*

The Morgan State group plans to collaborate with ARL scientists to use computer simulations in the

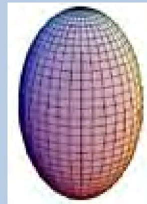
Terms and Explanations

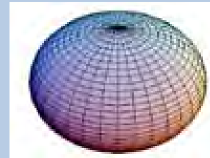
Beamforming is a signal processing technique that uses interference to change the directionality of an array.

Domain decomposition methods solve a boundary value mathematical problem by splitting it into smaller independent boundary value problems on subdomains and iterating to coordinate the solution between the subdomains—making the problem amenable to solution by parallel computing.

In *primal methods*, the continuity of the solution across a subdomain interface is enforced by representing the value of the solution on all neighboring subdomains by the same unknown. FETI (a *dual method*) enforces this continuity using Lagrange multipliers. The FETI-DP method is hybrid between a dual and a primal method.

Finite element analysis, a computer simulation technique, represents an object or system using linked, simplified representations of discrete regions on an unstructured grid. The accuracy of the method can be improved by refining the mesh in the model using more elements and nodes. *(See figure on previous page.)*





Prolate (left) and oblate (right) spheroids. (Wikimedia Commons)

A *phased array* is a group of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions.

A *Rotman lens* is a pair of parallel plates that functions like a lens to focus microwave or millimeter wave energy. Elelctromagnetic energy enters a focal port and emerges from the antenna elements to produce a beam in a specific direction.

design and optimization of a series of antenna systems with millions of components, thus demonstrating the problem-solving potential of the CEM code.

Wilkins' research group is implementing previously-investigated techniques that employ a hybrid edge element approach, which is used to represent all electric field components in the region of interest in guided-wave structures. The group intends to determine the corresponding electromagnetic field behavior for propagating and decaying modes in waveguides with irregular cross sections, for which analysis with standard techniques proves to be extremely difficult. An algorithm will be developed and implemented to account for the field behavior in these regions by considerations of the variation in both location and direction of the materials within the waveguide. Additional considerations will include the modification of the mesh element type for regions where extremely thin layers are used, as well as modifications in the vicinity of a perfect electric conductor.

Talabi and Wilkins have started an investigation of the behavior of internal and external electromagnetic fields for a variety of configurations, most generally known as the generic prolate spheroid. The focus of this research is the derivation of a general solution in closed form for this type of configuration with the long axis parallel to the electric field vector of an incident plane-polarized electromagnetic wave. The prolate spheroid may be considered with a range of essential shapes, including a fiber cylinder, for which the aspect ratio (length versus diameter) is extremely high. (At the other extreme is the oblate spheroid, often referred to as a "flat pancake." In the middle of these two extremes is the spherically-shaped particle.)

As an initial assumption, frequencies corresponding to wavelengths much greater than the dimensions of the particle are being considered for the fiber cylinder, with an update of the solution to wavelengths on the order of the dimensions of the particle. Ideally, the frequency range will be from the megahertz to infrared

continued on page 11

Information Networks

continued from page 3

network by minimizing energy use and communicating only when necessary—radio communications are by far the most energy-consuming network operations. In a more literal sense, lightweight network nodes must be small enough to be carried by soldiers (along with their other gear) in an adversarial environment.

The nodes must rely on portable power sources, usually batteries. When a battery dies, the node dies with it. Guibas notes, "such a death can be more detrimental than just the loss of the data and sensing capabilities of the node involved; a node failure can limit the bandwidth or even disconnect the network, with more severe global consequences."

Progress to Date

The research group is analyzing distance-sensitive algorithms for information brokerage using both theory and HPC simulation. They are investigating localized information aggregation, algorithmic enhancements to adapt all the protocols to changing environmental conditions and to user mobility patterns, and exploitation of HPC resources for network design, data mining, and network adaptation.

So far, the group has evaluated options for wireless node hardware, sensor boards for the nodes, and operating systems and programming languages. They are formulating basic information brokerage architecture and scenarios, and they are designing and implementing a simulator, with the intention of making it stable and scalable.

Later this year, they will design and simulate basic information brokerage mechanisms. They will develop and test low-latency information delivery techniques (routing with load balance) for static and mobile destinations. They will implement signal compression on mote (sensor node) hardware and methods for browsing remote sensor data. They will complete a stable and scalable simulator, and they will implement and demonstrate a small test-bed with real nodes.

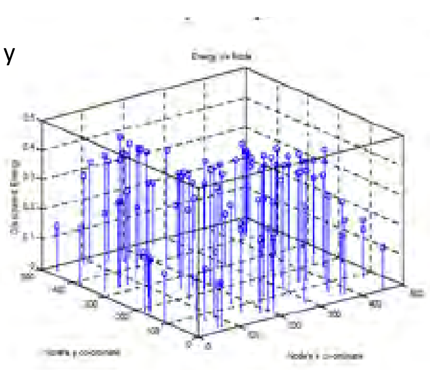
As the project progresses, the research team will explore basic algorithmic trade-offs in information storage vs. ease of access, and they will design the architecture of a "data annotation and recommendation" system for mobile users. ✯

Secure Data

continued from page 7

Over the next few months, the researchers plan to study the interaction of in-network processing, security function, and network parameters such as topology, channel condition, and MAC contention (a protocol for avoiding data packet collisions in medium access control networks). They will work on optimizing the tradeoff between in-network processing and security functions using simulation and analysis. They are also developing an analytical formulation of spatial obfuscation using entropy. They will be developing a simulation using a protocol synthesis approach, and integrating their work with a temporal obfuscation that they developed last year. ✯

Dissipated energy (vertical axis) vs. x and y node coordinates



Wireless Communications

continued from page 5

for the "interference management" schemes that they developed in 2007. They will complete a scalable PHY layer simulator for battlefield networks to explore interference and TR-enabled schemes, and they plan further developments in interference-aware scheduling techniques. The team will do experimental assessments of TR leverage in secure communications in urban scenarios, and they will study how to adapt fourth-generation (4G) mobile wireless systems such as WIMAX, LT, and UMB to MANET applications.

Technological innovations and increased understanding of wireless communications networks gained as a result of this project could be used to improve and advance such DoD applications as geolocation, imaging, radar, sonar, and lidar. Spinoffs from these technologies could be applied to improvements in imaging and sensing capabilities.

Modern physical layer technologies such as OFDMA, MIMO and OS can enable reliable, high speed, multi media links within a large, and dynamic, mobile network of users, while meeting low power constraints. Furthermore, time reversal techniques may offer ways to exploit the multi-path to reduce co-channel interference to friendly users while reducing the probability of interception. Such goals are rarely of interest in commercial wireless communications, which are designed to operate under highly predictable and controlled environment. The design of battlefield communications system requires intense computing resources and therefore can significantly benefit from high performance computing technologies. ✯

References:

(*1*) S. M. Emami, J. Hansen, A. D. Kim, G. Papanicolaou, A. J. Paulraj, D. Cheung, and C. Prettie. Predicted Time Reversal Performance in Wireless Communications Using Channel Measurements, *IEEE COMLET,* 2002 (Available at ftp://math.stanford.edu/pub/papers/papanicolaou/ComLet.pdf)

(*2*) Arogyaswami Paulraj. *Ask the Expert*: What is WiMAX?, 2006. (Available at http://soe.stanford.edu/research/ate_paulraj.html)

Antenna Simulations

continued from page 9

ranges ("DC to daylight"). Solutions are being generated for the internal and external electromagnetic fields that are written in terms of the physical variables of the problem (particle conductivity, permeability, and dimensional parameters, and the frequency and polarization of the incident wave). This type of research is beneficial in that it allows for the study of a wide variety of antenna configurations with irregular shapes, which may be grouped together for beam steering purposes (referred to as phased arrays).

Ongoing simulation work includes the application of Ansoft's High Frequency Structure Simulator to a Rotman Lens beamforming network. The continuation of this project will employ domain decomposition as an added feature. The results using domain decomposition will be compared with the results of simulations that do not use the added feature.

Army and Civilian Applications

In conjunction with the ARL Adelphi Sensors and Electron Devices Directorate, students are being recruited to work on the design of antenna architectures suitable for conformal application to Army platforms in support of system requirements, including receive-only broadband antenna systems and antenna arrays.

This research supports the investigation of factors that can limit the performance of very-large-scale-integrated antenna networks. Sensor networks incorporated into spaces such as homes, cars, stores, roads, or cities must take into account mobile users distributed in the same space as the network. Other factors that must be addressed include rapid information aging, cross-interference from the concurrent operation of multiple networks (cellular, WiFi, WiMax), and serious security and privacy concerns. By developing the tools and methods to assess such situations, this HPC project can identify and optimize the factors necessary to construct and maintain these complex networks in a variety of environments. ✯

AHPCRC Tech Area 3 Research Team

Tech Area Lead: George Papanicolaou

Principal Investigators:

Information Aggregation and Diffusion in Networks
Leonidas Guibas
Computer Science Department
Stanford University
guibas@cs.stanford.edu
(650) 723-0304

Robust Wireless Communications in Complex Environments
Arogyaswami Paulraj,
Electrical Engineering Department
Stanford University
apaulraj@stanford.edu
(650) 725-8307

and
George Papanicolaou
Mathematics Department
Stanford University
Stanford, CA 94305
papanicolaou@stanford.edu
(650)723-2081

Secure Data Dissemination and Aggregation
Amiya Bhattacharya
Department of Computer Science
New Mexico State University
amiya@cs.nmsu.edu
(575) 646-6230

and
Hong Huang
Klipsch School of Electrical and Computer Engineering
New Mexico State University
Las Cruces, NM 88003 USA
hhuang@nmsu.edu
(575) 646-3639

Parallel Solvers for Complex Antenna Simulations
Gregory Wilkins
Electrical & Computer Engineering Department
Morgan State University
Baltimore, MD 21251
gwilkins@eng.morgan.edu
(443) 885-3915

and
Charbel Farhat
Mechanical Engineering Department
Stanford University
cfarhat@stanford.edu
(650) 723-3840

AHPCRC Launches Research and Operations Center

On November 29, 2007, dignitaries and key staffers were on hand for the launch of the Army's supercomputing and research presence in the heart of Silicon Valley. The foundation of the Army High Performance Computing Research Center is provided by the supercomputing and research facilities at Stanford University and at the NASA Ames Research Center at Moffett Field, near Mountain View, California.

Guests gathered at Stanford University, the lead academic organization in the AHPCRC consortium, where they heard presentations and remarks by several of the persons who played key roles in making this consortium possible. At Stanford, a 1,600-core Dell cluster supercomputer is dedicated to Army research projects, and a majority of AHPCRC's research projects are led by Stanford faculty members. Afterward, the guests were treated to a tour of AHPCRC's research facilities at the Ames Research Center, which hosts two Cray supercomputers, offices, and collaboration space on behalf of the AHPCRC Consortium.

Among those attending and speaking at the event:

- Dr. John L. Hennessy, Stanford University President
- Major General Fred D. Robinson, Jr., Commanding General of the U.S. Army Research, Development and Engineering Command (RDECOM)
- Dr. John A. Parmentola, Army Director for Research and Laboratory Management
- Dr. Raju Namburu, Associate Director, Computational and Information Sciences Directorate and AHPCRC Cooperative Agreement Manager
- Dr. Charbel Farhat, Stanford Professor of Mechanical Engineering and, by courtesy, of Aeronautics and Astronautics, and AHPCRC Center Director

Hennessy, a computer scientist by training, spoke of the unanticipated benefits of basic research. He reminded the audience that when the TCP/IP protocol was developed at Stanford in the early 1970s, no one knew that it would eventually become the foundation of the Internet. Robinson reminded his audience that we are all warfighters, not just those in uniform. Warfighters are also the people who support the troops, and that all who are invested in this program should think of themselves as such.

Parmentola summarized the major AHPCRC project areas and explained their relevance to the Army's stated needs. The Stanford News Service reports Parmentola stating that a smaller, faster military requires the development of new materials. These materials could reduce the weight of a soldier's pack from 100 pounds to 40 or slash the bulk of an armored tank from 70 tons to 20. The work must begin with simulation of the behavior of materials at the atomic and molecular level, he said. He noted that "every general would like to have" a Star Trek-like holodeck, where holographic avatars could represent their human counterparts in virtual meetings. Parmentola envisioned hummingbird-sized aerial drones that soldiers could toss into the air. These drones would fly off on autonomous surveillance missions, all the while "networking by swarming."

Farhat concluded the opening remarks and showed a video animation illustrating the vision for the research center, and he gave a review of each research area in the program. ✯

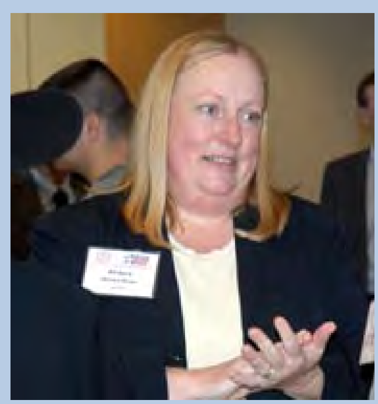
more photographs on pages 14 and 15

Entrance to the NASA Ames facility.

Front row: Dr. Raju Namburu (ARL), Maj. Gen. Fred Robinson (RDECOM), Dr. Charbel Farhat (Stanford), Dr. John Parmentola (Army), Ms. JoAnne Isham (HPTi, COO), Mr. Mark Thompson (HPTi, Program Manager). Back row: Mr. Charles Nietubicz (Director, Major Shared Resource Center, Aberdeen), Dr. Windell Ingram (Chief, Computer Science Division, ARL-ITL), Mr. John Miller (Director, ARL), CSM Hector Marin (RDECOM), Lt. Col. Fredrick Ludden (Military Deputy, ARL-CISD), Dr. Bryan Biegel (Chief, NAS Research Branch), Mr. Scott Miller (HPTi VP, Advanced Systems).

Left: Operations Manager Charles Peavey (HPTi), Robinson, Miller, Farhat, Parmentola, Biegel

Right: Farhat, Stanford President John Hennessy, Parmentola



Above: AHPCRC User Services Manager Barbara Bryan (HPTi)

Morgan State University Hosts Computing Academy

At Morgan State University (Baltimore, MD), the Academy in Computing introduces pre-college students to the many applications of high performance computing tools and techniques. Morgan State University, a member of the AHPCRC consortium, established this academy in autumn 2007 as its AHPCRC academic-year outreach component. During this initial session, 50 students spent eight hours every Saturday for ten weeks learning about computer-related applications that addressed weather prediction, global climate change, homeland security, space technology, genetic manipulation, and other related topics.

Under the supervision of Myra Curtis, Retention Support Specialist, and with a cadre of current undergraduate assistants, participants are learning about key occurrences in the evolution of computing, how these occurrences helped define the state of computing today, and where the field might be heading. Instructors introduce core principles of teamwork, personal time management, the development of leadership skills, and critical thinking practices. Participants also gain hands-on experience and are planning curriculum-related field trips.

The Computing Academy requires that each student be afforded an opportunity to assemble a computer that will be used as a critical resource in their subsequent participation in future phases of the Academy. The future phases will include programming, networking, concepts of distributed computing, and progressive complexities of computing through actual modeling and simulation of phenomena.

The program includes an assessment component geared towards maximizing impact and effectiveness in knowledge transfer and appreciation for high performance computing by students from a variety of backgrounds, including those from predominantly minority and underserved urban communities.

Students are introduced to the concept of problems where the number of unknowns is typically on the order of thousands, perhaps millions or billions. They learn about iterative computing processes requiring large amounts of memory and fast computational time. In addition, they learn about developments in the visualization and interpretation of the results of these complex calculations.

As students participate actively in design projects, they learn how to work responsibly in teams, develop leadership skills, and learn about time management. They attend classes that enhance their skills in mathematics as well as English, with a focus on critical thinking, writing, and speaking skills.

The learning goes both ways—the mentors, students in the School of Engineering, coordinate and operate the Saturday Academy program, in collaboration with the pre-college program director. Through planning, developing, and implementing the Academy programs, they learn skills in leadership, teaching, and teamwork. This experience also involves them actively with the administration of the School of Engineering and helps them plan their future careers.

Students have returned for the Spring 2008 semester, ready to continue learning aspects of computing such as building personal computers from kits, installing and understanding operating systems, and an introduction to fundamental programming skills. A similar program will be developed for the Summer 2008 session. ✯

The Saturday Academy

The Saturday Academy, of which the Computing course is one part, is sponsored by the Morgan State University School of Engineering. It offers educational enrichment programs to schools in the Baltimore City Public School System as well as public and private schools in the Baltimore metropolitan area. These programs focus on science, technology, engineering, and mathematics (STEM).

Since the Academy's inception in the 1995–1996 school year, more than 500 participating students have come to the Morgan State campus for this program. In addition to getting a taste of a college campus environment, the students interact with college student mentors and learn about the everyday applications of STEM.

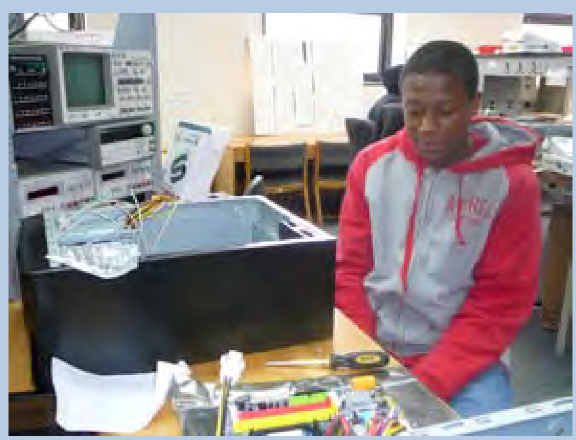
The Saturday Academy is designed to increase:

- science, technology, engineering, and mathematics career awareness;
- academic performance in the classroom, with the intention of increasing retention rate in the classroom;
- student performance on national, state, and local performance tests in the areas of science, mathematics, reading, and writing;
- the number of minority students pursuing higher education; and
- the number of students who major in science, technology, engineering, and mathematics.

The program stresses the art and science of problem solving. The science side stresses the learning

and appropriate application of knowledge of the principles of mathematics, chemistry, physics, mechanics, and other technical subjects. This approach, combined with proper judgment, experience, common sense, and know-how, can be used to reduce a real-life problem to such a form that science can be applied to its solution.

Students are taught to study and analyze problem statements, estimate solutions, apply mathematical equations, then check their results to see if they make sense. They learn engineering approaches to problem-solving, such as constructing models, applying mathematical methods, and interpreting their results in physical terms. They learn to define and characterize problems, work within constraints and specifications, postulate fundamental relations, and search for alternative solutions. ✫



Pre-college students build computers from kits at the Morgan State University Academy in Computing.

Publications and Presentations

Distribution Statement A: Approved for public release; distribution is unlimited.

2008

Project 3–1: Information Aggregation and Diffusion in Networks
Primary Investigator: Leonidas Guibas

R. Sarkar, X. Zhu, J. Gao, L. J. Guibas, J.S.B. Mitchell. Iso-Contour Queries and Gradient Descent with Guaranteed Delivery in Sensor Networks. 2008 INFOCOM.
http://www.ieee-infocom.org

H. Lin, M. Lu, N. Milosavljevic, J. Gao, L. J. Guibas. Composable Information Gradients in Wireless Sensor Networks. 2008 IPSN.
http://ipsn.acm.org/2008

Project 3–3: Secure Sensor Data Dissemination and Aggregation
Primary Investigators: Amiya Bhattacharya and Hong Huang (New Mexico State University)

Venkata Kodali, Yughandhar Katuru, Hong Huang, Amiya Bhattacharya. SDDA: Sparse and Dynamic In-Network Data Aggregation in Sensor Nets. Abstract submitted to IEEE Milcom 2008.
http://www.milcom.org/TechnicalPapers.asp

Somdev Chatterjee. A protocol synthesis approach to enhance privacy in networked sensing. Poster presentation at the NMSU Graduate Research and Arts Symposium, April 2–3, 2008. A less technical presentation is planned for high school students attending the NMSU computer science summer camps.

Project 4-1: Stream Processing for High Performance Computing
Primary Investigators: William Dally and Pat Hanrahan (Stanford University)

M. Houston, J.-Y. Park, M. Ren, T. Knight, K. Fatahalian, A. Aiken, W. Dally, and P. Hanrahan. A Portable Runtime Interface for Multi-Level Memory Hierarchies. *Proceedings of the Symposium on Principles and Practice of Parallel Programming*, February 2008.
http://portal.acm.org/citation.cfm?doid=1345206.1345229

2007

Project 1-4: Flapping and Twisting Aeroelastic Wings for Propulsion
Primary Investigators: Charbel Farhat (Stanford University), James Allen, Banavara Shashikanth, and Mingjun Wei (New Mexico State University)

Mingjun Wei (presenter, New Mexico State University), Clarence Rowley (Princeton University); American Physical Society, 60th Annual Meeting of the Division of Fluid Dynamics, 18–20 November 2007; Salt Lake City, Utah; Low-dimensional modeling for both temporally and spatially developing free shear layers.
http://meetings.aps.org/Meeting/DFD07/Event/71710

Mike Harff, Haibo Dong (Wright State University), Mingjun Wei (New Mexico State University); American Physical Society, 60th Annual Meeting of the Division of Fluid Dynamics, 18–20 November 2007; Salt Lake City, Utah; On the Optimal Settings of Performance Parameters in Hovering MAV Flight.
http://meetings.aps.org/Meeting/DFD07/Event/72681

Jeremy Pena, Scott Hightower, James Allen, Paulo Ferreira de Sousa, Banavara Shashikanth (New Mexico State University); American Physical Society, 60th Annual Meeting of the Division of Fluid Dynamics, 18–20 November 2007; Salt Lake City, Utah; Experimental results of harmonically oscillating flexible and rigid flat plates.
http://meetings.aps.org/Meeting/DFD07/Event/72463

Paulo Ferreira de Sousa, James Allen (New Mexico State University); American Physical Society, 60th Annual Meeting of the Division of Fluid Dynamics, 18–20 November 2007; Salt Lake City, Utah; Axisymmetric interaction between a laminar vortex ring and a sphere—stationary sphere case.
http://meetings.aps.org/Meeting/DFD07/Event/72588

Jose Carlos Pereira (Department of Mechanical Engineering/LASEF, Instituto Superior Tecnico), Paulo Ferreira de Sousa (New Mexico State University); American Physical Society, 60th Annual Meeting of the Division of Fluid Dynamics, 18–20 November 2007; Salt Lake City, Utah; High-order fluid/structure coupled numerical model.
http://meetings.aps.org/Meeting/DFD07/Event/71826

Banavara Shashikanth (presenter, New Mexico State University), Artan Sheshmani (UIUC), Scott Kelly (UIUC), Mingjun Wei (New Mexico State University); 2007 Interdisciplinary Transport Phenomena V, 14–19 October 2007; Bansko, Bulgaria; Hamiltonian structure and dynamics of a neutrally buoyant rigid sphere interacting with thin vortex rings.
http://ame-www.usc.edu/cf/Bansko2007/PROGRAM/Paper-26.pdf

Project 2-3: Protein Structure Prediction for Virus Particles
Primary Investigator: Jing He (New Mexico State University)

Jing He, Kamal Al Nasr (New Mexico State University); IEEE BIBM Workshop in Computational Structural Bioinformatics, 2–4 November 2007; Silicon Valley, CA; An approximate robotics algorithm to assemble a loop between two helices.
http://www.cs.nmsu.edu/~xqin/bioworkshop/bioworkshop.htm

Yonggang Lu, Charlie E. M. Strauss, and Jing He (New Mexico State University); IEEE BIBM Workshop in Computational Structural Bioinformatics, 2–4 November 2007; Silicon Valley, CA; Incorporating constraints from low resolution density map to ab initio protein structure prediction using Rosetta.
http://www.cs.nmsu.edu/~xqin/bioworkshop/bioworkshop.htm

Project 3–3: Secure Sensor Data Dissemination and Aggregation
Primary Investigators: Amiya Bhattacharya and Hong Huang (New Mexico State University)

Hong Huang (New Mexico State University); "Distributed Computing in Wireless Sensor Networks," in *Encyclopedia of Mobile Computing and Commerce* ed. David Taniar, Information Science Reference, Hershey, PA, 2007.
http://www.igi-pub.com/reference/details.asp?id=6453

H. Huang and Bhattacharya, "Secure sensor data dissemination and aggregation," Poster, SC2007.
http://sc07.supercomputing.org/?pg=posters.html

H. Huang and Bhattacharya, "Secure in-network processing in wireless sensor networks," Poster, High-End Computing along the Rio Grande, SC2007.
http://sc07.supercomputing.org/?pg=posters.html

Venkata Kodali, "Probabilistic data aggregation and security in wireless sensor networks," MS Thesis, EE Dept., NMSU, Dec. 2007.

Rama Rani Pulimamidi, "Impact of sensing parameters on the tradeoff between detection performance and energy consumption in sensor networks." MS Tech Report, EE Dept., NMSU, Dec. 2007.

Project 4-6: Hybrid Optimization Schemes for Parameter Estimation Problems
Primary Investigators: Miguel Argáez, Leticia Velázquez, and Patricia Teller (University of Texas at El Paso)

Leticia Velázquez (University of Texas at El Paso); 6th International Congress on Industrial and Applied Mathematics (ICIAM 07), 17 July 2007; Zurich, Switzerland; A hybrid optimization approach for solving automated parameter-estimation problems.
http://www.iciam07.ethz.ch/timetable/web/symposium.php?nr=IC/MP/067/U/295&slot=25&db=timetable ✮

Distribution Statement A: Approved for public release; distribution is unlimited.

Army High Performance Computing Research Center

c/o High Performance Technologies, Inc.
11955 Freedom Drive, Suite 1100
Reston, VA 20190-5673
ahpcrc@hpti.com
703-682-5368

INSIDE:

This work was made possible through funding provided by the U.S. Army Research Laboratory (ARL) through High Performance Technologies, Inc. (HPTi) under contract No. W911NF-07-2-0027, and by computer and software support provided by the ARL MSRC.

US ARMY RDECOM

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.